Auralization of noise recordings behind a simulated noise barrier

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Introduction

Due to increasing traffic and regulations specifying lower noise levels, noise barrier heights are being increased in Austria and other countries. The increasing height disturbs the free sight into the environment. Outward bended noise barriers with high absorptive material can reduce the noise with respect to a straight noise barrier.

Calculations based on the boundary element method in two dimensions were made. The results of the calculations are the insertion losses on a grid behind the noise barrier. At the reference position of 25m distance and 2m height (Figure 1), the calculated spectral insertion loss is used as a filter for the measured noise of a motorway or railway line to simulate the noise behind the noise barrier.

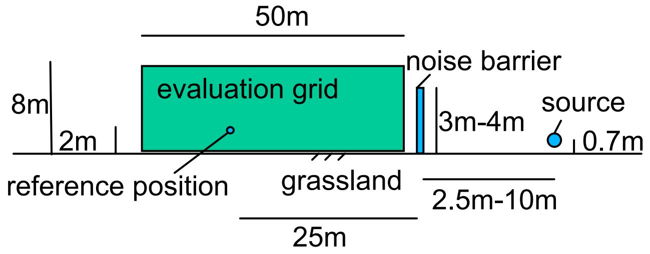

Figure 1: Noise barrier, source and reference position

Boundary Element Method (BEM)

The usual ray tracing method is insufficient for simulating the insertion loss behind a backward tilted wall. Therefore the boundary element method was used. The computational efforts are high.

The surface was simulated by a two parametric model for grassland originally developed by K. Attenborough [1]. The model was implemented in a Green's function, resulting in smeared sources [2]. This effect hinders the application of the fast multipole method since no distinct separation of near-field and far-field is possible. To keep the matrix small enough for the calculation, the simulations are limited to two dimensions.

Using the grassland model, only the noise barrier had to be discretized. For tests, the lane of the motorway was a reflecting surface of discrete elements. Using this surface or not make negligible difference behind the wall. The computational efforts, however, increased rapidly. Therefore, the reflecting surface omitted in the majority of the computations. The noise barrier itself was simulated using variable polynomial degrees for the ansatz functions of every surface element. This allowed the use of the same grid in the low-frequency and the high-frequency region.

Noise barrier types

Eight noise barriers were investigated (Figure 1). The light blue parts have a high absorption coefficient of 0.9. The absorption coefficient was converted to a complex impedance where the phase was assumed. The complex value used is 1.378705+0.685085i. The dark blue parts are reflecting. The source is on the right side of the noise barriers. The names of the noise barriers are selected with respect to the place where they will be installed.

All noise barriers have a height of 3m. Only type Nürnberg 4m has a height of 4m to allow for a comparison of the additional insertion loss of the curved wall to a 1m higher straight wall.

S35-B is a transparent wall which is totally reflecting. It was simulated using middle-face elements. The insertion loss of this wall was drastically lower than that of those simulated by surface elements. Since it could not be proven whether the usage of middle-face elements was responsible for the results, this wall was not taken into account in the final evaluation.

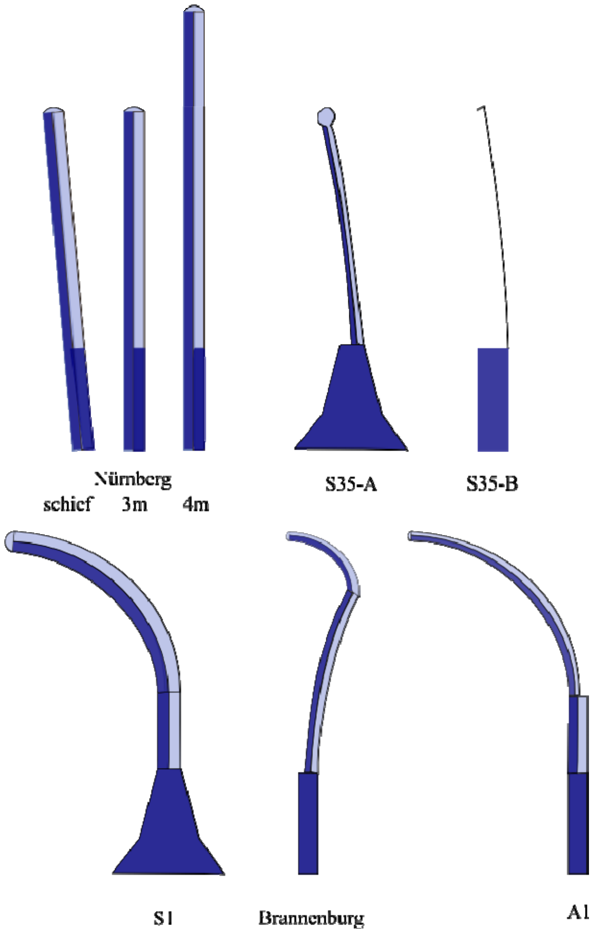

Figure 2: Noise barriers used in the simulation

Insertion loss of the noise barriers

The insertion loss of the noise barriers was calculated on a grid that starts directly behind the noise barriers and extends for 50m. The height is from 0m up to 8m. The grid-points are have a distance of 50cm apart (Figure 3). The insertion losses present local maxima and minima that vary with frequency due to the interference effects at the noise barrier.

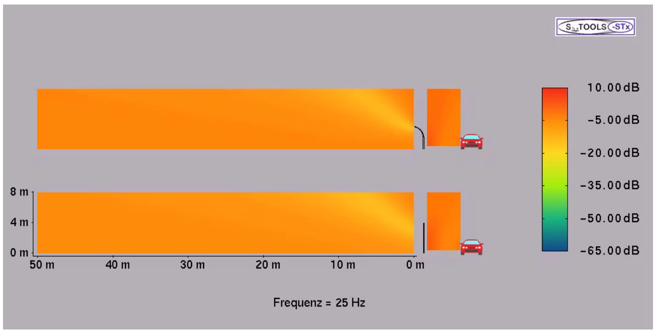

Figure 3: Insertion loss of noise barrier A1 compared to Nürnberg 4m

Due to the different interference effects of the different noise barriers, the calculation of the insertion loss is difficult. The result defers from place to place. To reduce this effect, the values are averaged over the grid. In positions that are above the noise barrier amplifications are visible. To get rid of these effects, a trapezoid is used that starts at the height of the noise barriers and ends at a height of 8m, at a distance of 50m from the noise barrier (Figure 4). All points of the evaluation grid are averaged to smoothed spectra of the insertion loss.

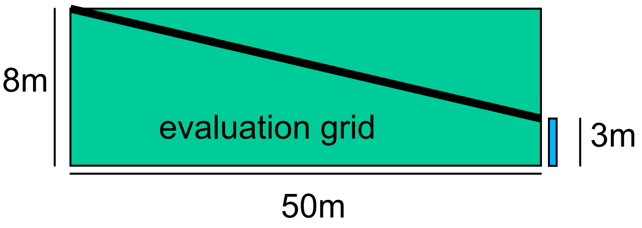

Figure 4: Evaluation grid

As an example, the insertion loss spectrum of the curved noise barrier A1 is compared with straight noise barriers Nürnberg 3m and Nürnberg 4m (Figure 5).

It is visible that the curved noise barrier A1 behaves like a 3m high straight noise barrier in the low frequency region, and like a 4m high noise barrier in the higher frequency region for a source distance of 5m (Figure 5). If the source distance is increased to 10m (Figure 6), the curved noise barrier behaves a little bit better than a 3m high noise barrier. The insertion loss of a 4m high straight noise barrier, however, is higher than that of a 3m high curved noise barrier.

Although the values are averaged over the evaluation grid, maxima and minima of the insertion loss are still visible.

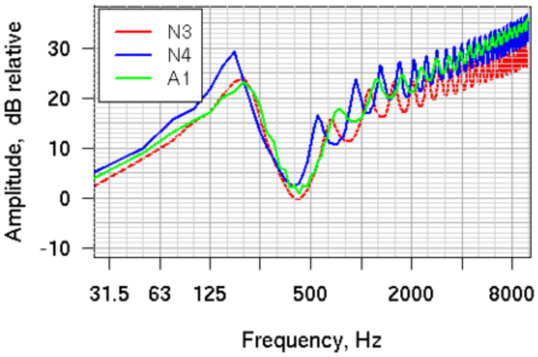

Figure 5: Insertion loss of noise barrier A1 compared to N3 (Nürnberg 3m) and N4 (Nürnberg 4m) – source distance 5m

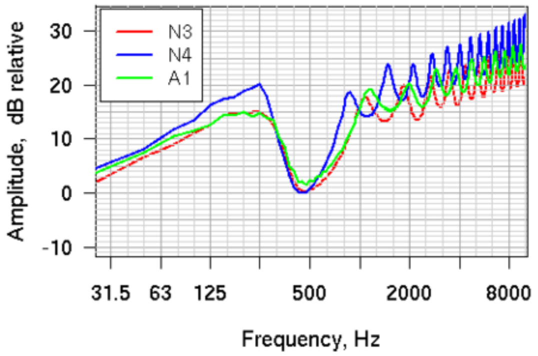

Figure 6: Insertion loss of noise barrier A1 compared to N3 (Nürnberg 3m) and N4 (Nürnberg 4m) – source distance 10m

Singular values of the insertion loss

In accordance with measurements done in an anechoic room, the spectral insertion losses were weighted with the noise emission measured at a distance of 7,5m from the road (Motorway A1 near Strengberg) and 25m from the railway (Westbahn near Pöchlarn). The response spectra were again weighted with the A-curve and energetically averaged over the frequencies. This was done separately for the case with and without a noise barrier. The quotient of these two values is the singular value of the insertion loss. Table 1 presents the singular values of the insertion losses for the different noise barrier types and source distances of 2,5m, 5m and 10m for railway and road noise. The insertion losses are higher than were measured in praxis. This might be the effect of missing reflections from the height at the air layers. A faster comparison is possible if Table 2 is taken into account. In this table, the differences with respect the 3m high straight noise barrier are presented. It is clearly visible that with increasing distance from the source, the curved noise barriers perform worse.

For small distances, the 3m high curved noise barriers perform as well as the 4m high straight noise barrier.

A slight curvature (S35-A) or a tilt (Nürnberg schief) does not provide an improvement on its own. A large curvature with a highly absorbing material is needed to be mitigating (S1, A1, Brannenburg).

type	railway			road		
source distance	2.5m	5.0m	10m	2.5m	5.0m	10m
S1	21.2	18.8	15.9	21.3	18.0	14.4
A1	21.3	18.7	15.7	21.7	17.9	14.3
Brannenburg	20.5	18.1	15.6	21.2	17.6	14.2
S35-A	18.8	17.1	14.9	18.9	16.4	13.6
Nürnberg schief	18.5	16.8	14.7	18.7	16.0	13.3
Nürnberg 3m	18.7	16.8	14.8	19.1	16.2	13.3
Nürnberg 4m	21.5	19.3	17.7	22.4	19.2	16.3

Table 1: Singular values of insertion loss in dB(A)

type	railway			road		
source distance	2.5m	5.0m	10m	2.5m	5.0m	10m
S1	2.5	2.0	1.1	2.2	1.8	1.1
A1	2.6	1.9	0.9	2.6	1.7	1.0
Brannenburg	1.8	1.3	0.8	2.1	1.4	0.9
S35-A	0.1	0.3	0.1	-0.2	0.2	0.3
Nürnberg schief	-0.2	0.0	-0.1	-0.4	-0.2	0.0
Nürnberg 3m	0.0	0.0	0.0	0.0	0.0	0.0
Nürnberg 4m	2.8	2.5	2.9	3.3	3.0	3.0

Table 2: Differences of insertion loss in dB(A) to the reference Nürnberg 3m

Comparison with measurements

A simple rough comparison of the calculated and measured insertion loss is possible, if the measurement data recorded at the motorway A1 are used. The data were recorded at a distance of 25m, with and without a noise barrier with a short delay in time, because the measurement positions behind the noise barrier and without a noise barrier had a gap of 100m along the road.

The minima of the measurements coincide with the measured data in the mid-frequency region, although no reflections from the air profile were taken into account in the calculation. In the high frequency region, the acoustic energy in the measurements was very low.

The measurements do not present maxima and minima as they were present in the calculation, due to the time averaging and averaging of different source positions. The reality that inclined noise exists which is not taken into account in a two dimensional calculation assuming a line source (Figure 7) must be kept in mind.

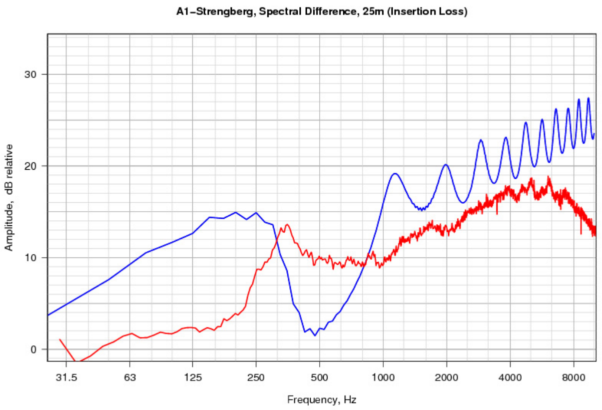

Figure 7: Comparison of insertion loss at A1 (Strengberg): red curve measurement, blue curve calculation

Generation of audible sounds

For the generation of audible sounds, the insertion loss spectra were calculated as complex spectra with a frequency step of 25Hz. This gap was selected since psychoacoustics usually uses a frequency step of about 22Hz. The BEM has, of course, to be calculated for every frequency step separately.

These spectra are used to filter the acoustic immission measurements that were made at the same position, 25m away from the track or the road, without a hindering noise barrier.

The recorded signals were transformed into the spectral domain using the fast Fourier transformation algorithm, with a time window length of 40ms, which corresponds to a frequency gap of 25Hz. A Hanning window was applied to reduce leakage.

The phase shift of the insertion loss spectra and the application of FFT wrap around lead to a distortion of the time signal. This distortion was minimized using 16-time oversampling.

A better way to reduce distortion is the application of the fast FFT filter defined by IEEE. Adding a zero window (zero padding) cancels the wrap around effects and no distortion is audible.

Psychoacoustic tests

To reduce the detection of separate events by the audience, the generated sounds were split into sequences of 10s length and averaged. The pass-by events for railway noise were separated in advance from the long pauses between them.

The results from the psychoacoustic tests are that the curved noise barriers perform a little bit better than the 4m high straight noise barrier Nürnberg 4m. This improvement is, however, insignificant.

Acknowledgement

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References

[1] K. Attenborough, Acoustic impedance models for outdoor ground surfaces. Journal of Sound and Vibration 99(4) (1985), 521-544.

[2] Z.-S. Chen and H. Waubke, A formulation of the boundary element method for acoustic radiation and scattering from two-dimensional structures. Journal of Computational Acoustics 15(3), 2007, 333-352